REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
20-07-2004

2. REPORT TYPE
Final Technical Report

3. DATES COVERED *(From - To)*
Jan. 21, 2004 - Jul. 20, 2004

4. TITLE AND SUBTITLE
The Miniaturized Autonomous Moored Profiler
Phase I Final Technical Report

5a. CONTRACT NUMBER
N00014-04-M-0056

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

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8. PERFORMING ORGANIZATION REPORT NUMBER
MiniAMP-I-4

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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10. SPONSOR/MONITOR'S ACRONYM(S)
ONR SBIR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
CLIN: 0001AD

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; SBIR report, distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
In this final technical report we have provided results of initial analyses into the design of a light-weight, autonomous, modular, bottom-up vertical profiling system named Mini AMP. The results of these analyses were used to produce a set of mechanical and electrical specifications and designs for the Mini AMP that emphasizes operational reliability, ease of use, and configuration flexibility. We believe that the results of this Phase I research effort demonstrate the feasibility of developing a Mini AMP system, positioning us to take this project to Phase II. We present a development pathway that will lead to the successful implementation and construction of the Mini AMP system. Our goal is to develop a multi-parameter, reliable, long-term vertical profiling capability that promise to significantly advance observational science and monitoring of coastal waters. The Mini AMP system will provide a reliable, easy to maintain, and rapidly deployable/recoverable solution to obtaining long term, high vertical resolution profiles of important physical and bio-optical properties in coastal regions.

15. SUBJECT TERMS
Autonomous moored profiler, sampling platform technology, integrated measurement suite.

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU		Barnard, Andrew
					19b. TELEPHONE NUMBER *(Include area code)* (541) 929-5650

Reset

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

1. Title Page

ONR SBIR Phase-I Final Technical Report (CLIN 0001AD)

Contract Title: **The Miniaturized Autonomous Moored Profiler (Mini AMP)**

Contract Number: N00014-04-M-0056

WET Labs Report No.: Mini AMP-I-4

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Performance Period: 20 January 2004 to 20 July 2004

Submitting Date: 20 July 2004

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2. Project Summary

We present a summary of Phase I efforts and a preliminary design of a compact, low power, autonomous, scalable, bottom-up profiling system termed the **Mini**aturized **A**utonomous **M**oored **P**rofiler (**Mini AMP**). The Mini AMP's novel design includes a robust suite of physical, biological and optical sensors, an integrated package control system, a power system, and an optional telemetry unit as a part of a modular, self contained, winch-driven profiling platform. The compact, hydrodynamic, low power design of the Mini AMP system will support a variety of long-term coastal applications, where real-time, high vertical resolution physical and bio-optical data are required. The overarching goal of this project is to provide a Mini AMP system that offers the customer a high level of flexibility in sensing parameters, data telemetry and data control, while maintaining a high level of performance, reliability, accuracy, and ease of use. Our Phase I research efforts focused on determining a design approach, assessing feasibility, and specifying the optimal system components needed to fulfill the desired functionality of the Mini AMP.

The prototype design developed in this Phase I research specifies a multi-parameter core sensor suite for the Mini AMP integration that includes an optical beam attenuation sensor, a rapid response CTD, fluorescence and backscattering sensors, and a spectral downwelling irradiance sensor. Multiple off the shelf telemetry systems were evaluated for potential integration with the Mini AMP. The modular design of the Mini AMP and the sophisticated package controller will allow any one of several telemetry options to be used with the system, providing bi-directional communications for profile scheduling and data retrieval capabilities from remote locations. The inherent configuration flexibility, extended deployment duration, high resolution and accuracy of the Mini AMP will provide revolutionary measurement capabilities of natural waters.

In this Phase I Final Technical Report, we provide a detailed description of the design specifications, the mechanical, electrical and hydrodynamic analyses that were performed, and a presentation of the prototype Mini AMP design. We believe that the capabilities of the Mini AMP design represent a significant innovation in sampling technology above and beyond the capabilities currently available from existing commercial profiling platforms. The Mini AMP system will provide an affordable, reliable, easy to maintain, and rapidly deployable/recoverable solution to obtaining long term, high vertical resolution profiles of important physical and bio-optical properties in coastal regions. Primary applications for the Mini AMP system include i) military operations, ii) coastal ocean observing systems, iii) long-term and episodic response water quality monitoring, and iv) wide ranging use by the research science community. The design results from this effort provide the basis for developing a set of modular components which will form the tools for future observing system platforms. In this feasibility analysis, we highlight the modular nature of the Mini AMP design which provides the user with a range of configuration options for their particular use.

3. Table of Contents

4. Review of Phase I efforts

4A. Overview

The objective of this Phase I research is focused on designing a compact, light weight, autonomous vertical profiling system to meet the needs of the military, research, and coastal monitoring communities. The **Mini**aturized **A**utonomous **M**oored **P**rofiler (**Mini AMP**) design criteria includes a suite of environmental sensors, an integrated data control system, a power unit, a winch and controller, and an optional telemetry unit as a part of a modular, autonomous, profiling platform. The Phase I work plan concentrated on developing a hydrodynamic, low power design for the Mini AMP system that will support a variety of long-term applications where real-time, high vertical resolution physical and bio-optical data are required. The design goal for the Mini AMP system is to offer the customer a high level of flexibility in sensing parameters, data telemetry, data control, and application use, while maintaining a high level of performance, reliability, accuracy, and ease of use thereby making the system inherently scalable. The compact light weight design of the Mini AMP system should facilitate a variety of possible deployment methods in coastal areas ranging from 3 to 100 meters.

During this design process, we also evaluated various existing profiler technologies. Most notably, an extensive design review of the ORCAS profiler developed by Dr Percy Donaghay and WET Labs was conducted with all team members in March, 2004. The ORCAS development embodied Dr. Donaghay's original concept of a winch-on-board profiler for monitoring fine-scale vertical structure of the water over week to month time scales. Several ORCAS prototypes have been developed and are now in service. The focus on the design review was not to identify pathways to improve the ORCAS profilers, but rather to identify system components that were robust and well implemented versus those that are problematic and error-prone. The information proved vital in advancing the Mini AMP design and capabilities. Other profiler designs including the McLane Research Laboratories, Inc. Moored Profiler (MMP), the Brooke Ocean Technology LTD SeaHorse™, and the InterOcean systems Inc. Autonomous Vertical Profiling System (AVPS) were also evaluated in terms of capabilities and functionality during the review process.

In this Phase I Final Technical Report, we provide a detailed description of the design specifications, the mechanical, electrical and hydrodynamic analyses that were performed, and a presentation of the prototype Mini AMP design. The overall shape and design of the Mini AMP was based on four primary factors; 1) positive buoyancy, 2) drag minimization, 3) package stability, and 4) sensor accommodation. Hydrodynamic, power budget, and form factor feasibility analyses were conducted to develop mechanical and electrical design criteria for the Mini AMP. The sampling capabilities and operational constraints of the Mini AMP were based on four broad application scenarios which are highlighted in this document. Defining these general scenarios allowed us to identify system components that require flexibility in configuration in order to meet the expected needs of these four broad user classes.

The results of these analyses were used to produce a mechanical and electrical design for the Mini AMP that emphasizes operational reliability, ease of use, and configuration flexibility. The primary embodiment of the Mini AMP design is first presented along with a detailed specification listing. Overviews of the design analyses and system component descriptions are presented in the

Design Analysis section. We believe that the results of this Phase I research effort demonstrate the feasibility of developing a Mini AMP system, and therefore position us to take this project to Phase II. A development pathway leading to the successful completion of the Mini AMP system is presented in the Preliminary Implementation Work Plan section.

4B. Mini AMP Primary Embodiment Design

Figure 1 shows a three dimensional schematic of the primary embodiment Mini AMP. The major components are the instrument and controller module, the expansion and telemetry bays, the power system, the winch system (motor, bale, and level wind), the buoyancy module, the support structure (backbone, ribs, and spar), and the faired shell. Each of these modular components is described in detail in section 6. The profiler has an airfoil shape in the vertical cross section, with a 9” diameter and a width of 15.75”. The length of the main body of the Mini AMP is 52.7”. A foam floatation collar, located at the top of the profiler, provides the Mini AMP with approximately 20 pounds of net positive buoyancy. The curved outer shell and tapered end fairing are constructed of molded polycarbonate plastic. The framework of the Mini AMP uses a structural fiberglass backbone, four aluminum mounting ribs, and a rear aluminum spar. The weight is distributed vertically across the profiler, with the heaviest components (winch and power system) located at the base, and the floatation at the top of the profiler, giving the profiler a weight distribution similar to a spar buoy.

An integrated **B**io-**O**ptical **S**ensing **S**ystem (**BOSS**) is located in a single pressure housing at the top of the profiler. In the primary embodiment of the Mini AMP, the optical instrumentation suite includes a combined single channel backscattering and fluorescence sensor (WET Labs ECO FLNTU), a spectral irradiance sensor (Satlantic Inc., OCR507 series), and a single channel beam attenuation sensor (based on the **S**cattering **A**ttenuation **M**eter, **SAM**, in development at WET Labs). The primary package controller electronics as well as the winch controller electronics are also housed in the BOSS. The primary controller manages sampling operation, power distribution, and data acquisition and winch control. A bio-wiper, based on proven anti-biofouling technology, is fully integrated with the optical instrumentation suite, to provide a single anti-fouling solution for all optical instruments. A rapid response CTD (SeaBird Electronics SBE49) with integrated pump completes the environmental sensing suite. Note that all sensors are located on the leading end of the profiler to minimize possible disturbance of the vertical structure of the water column during the profiler’s ascent. An end connector flange on the BOSS provides for optional serial, analog and switched inputs.

The middle section of the Mini AMP provides for instrument suite expansion as well as remote telemetry. In the primary embodiment of the Mini AMP, these sections are currently not used, but could easily accommodate a wide range of sensors and telemetry options, as well as additional floatation and power systems. The additional payload bay and telemetry bay volumes are 827 and 106 in^3 respectively. A self contained power module, with an external connector and a pressure relief valve, is mounted between two aluminum ribs located near the base of the profiler. Lithium/bromide chloride D cell battery stacks connected in series and parallel in the power module provide two power sources (13 V and 41 V nominally).

The winch system incorporates a NEMA-23 type drive motor with a worm gear for right angle translation, winch shaft, housing, bale, level wind and a spring loaded dynamic tensioning device.

The winch is mounted to the structural backbone of the Mini AMP using vibration and shock control mounts. The length and diameter of the bale can accommodate various types of wires or fiber-based lines. In the primary embodiment, Spectra® rope is used. The advantage of using Spectra® rope is that it provides very high strength, low stretch, excellent abrasion resistance and is slightly positively buoyant in water.

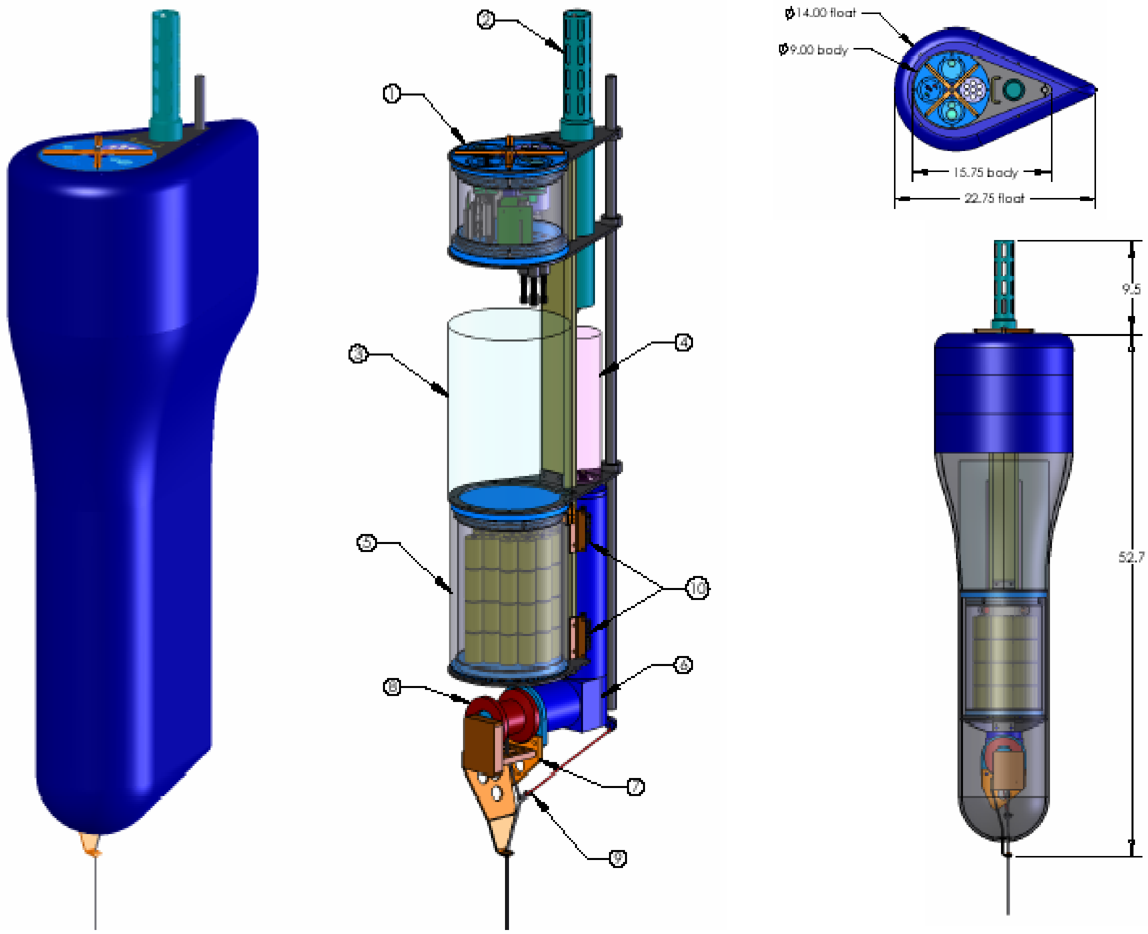

Figure 1– Three dimensional schematic diagram of the Mini AMP system. The profiler with the floatation and outer skin removed is shown in the middle panel. Components of the Mini AMP are labeled; 1) the bio-optical sensor system (BOSS) module, 2) the CTD (SeaBird Electronics SBE49), 3) the expansion bay (area highlighted to denote location and volume), 4) the telemetry bay (area highlighted to denote location and volume), 5) the power module, 6) the right angle winch motor, 7) the winch level wind, 8) winch bale, 9) dynamic wire tensioning device, and 10) winch system shock mounts. The dimensions in the horizontal and vertical plane are shown in the left panel. All units are in inches.

The platform is designed to perform vertical profiles in coastal waters (water depths $\leq$ 100 m) with horizontal current speeds up to 1 m s^{-1}. The profiling ascent and descent rates are user programmable accommodating vertical speeds ranging from 2 to 100 cm s^{-1}. The package controller, normally in sleep mode, activates the profiling sequence at user defined intervals, powering the winch system and instrumentation suite. Environmental instrumentation is powered during the ascent only for undisturbed measurement of oceanic properties. At the top of the ascent the package controller turns off power to the instrument suite. During the descent profile, the

winch motor is operated at an increased speed to lower the platform back to its resting state near the bottom. The package controller then powers down the winch motor and controller and enters a low power sleep mode. All collected data is stored on a flashcard memory module for later retrieval or remote transmission. With the optical telemetry installed the user controls the telemetry interval, data compression, and data decimation algorithms.

4C. Key Innovations

The key innovation of the Mini AMP is its modular, compact, light-weight design that provides an unparalleled level of flexibility in sensing parameters, telemetry, and operational configurations in one self-contained platform (Table 1). The design of the Mini AMP has considerable advantages over previous/existing prototypes and other commercial autonomous profiler systems. For example, the Mini AMP is a self-contained system, where all components with the exception of the anchor, are completely contained within the profiling platform. This significantly simplifies the recovery and deployment of the system, as well as improving reliability, as the winch is not in contact with the bottom. Bottom mounted winch profiling systems are often large, difficult to deploy and recover, and may suffer from clogging of the winch due to sediment resuspension and settling. Equally importantly, bottom mounted winch systems require two power systems or a system for communicating instructions between the package and the winch. In contrast, the entire Mini AMP system including the anchor can be easily deployed and recovered from a small boat by two people. The self-contained design of the Mini AMP also means that no permanent surface or subsurface floatation and mooring cable are required. Profilers that utilize a taught mooring wire to traverse the water column are highly susceptible to entanglement with fishing and trawling gear. Permanent surface expressions may also be very undesirable in many naval applications. The Mini AMP can be configured such that surfacing of the package is only required during deployment and recovery, by operating in a truly autonomous mode (no telemetry) or by using acoustic telemetry systems for remote transmission.

The design and drive electronics of the Mini AMP allow for a wide range of vertical profiling speeds to be achieved. By locating the core suite of bio-optical and physical instrumentation (sampling at intervals of 4 Hz or greater) near the top of the profiler, all measurements are obtained on a similar vertical plane. These two factors allow the Mini AMP to obtain fine vertical scale resolution measurements with minimal perturbation of the sampled water column during the ascent profile. The design gives the Mini AMP the capability to measure vertical features ranging from thin layers (10’s of cm) to bulk water masses, a capability lacking in other autonomous vertical profilers.

The Mini AMP system represents an advancement of prototype profiler technology that was co-developed by WET Labs, Percy Donaghay of the University of Rhode Island, and Alfred Hanson of SubChem Inc. through a National Oceanographic Partnership Program (NOPP) grant. The ORCAS profiler prototypes developed in this project demonstrated the utility of in using autonomous profiling technology to observing the fine scale vertical structure. However, these prototypes have limitations that make them ill suited for operational oceanography, tactical Naval deployments, and ultimately, a viable commercial product for WET Labs. These included limited deployment duration (weeks), highly customized payloads, limited telemetry capabilities, and limited operational range (< 50 m water depth). The Mini AMP is designed to surpass the functionality of the ORCAS profilers and to offer the user a broad range of configuration and operational capabilities. We are confident

that design of the Mini AMP developed in this Phase I effort will lead to commercially viable product that will service a broad range of needs.

Table 1 – A summary of the innovations of the Mini AMP design

INNOVATION	BENEFIT
Self-contained, modular sampling platform	All components of the profiling system are a part of the sampling platform, facilitating easy deployment and recovery. The modularity of the platform allows for rapid servicing and repair as well as for additional payload expansion.
No permanent surface expression or mooring cable	The integration of the winch and wire on the profiling platform negates the need for a permanent surface buoy and mooring cable. This mitigates potential accidental entanglement associated with ship traffic and fishing activities and allows for stealthy operation.
Integrated anti-fouling	Proven anti-fouling devices are fully integrated with the sensor suite enabling long-term deployment capability. The platform is stationed near the bottom of the water column between sampling periods, out of the productive surface waters.
Flexibility in sensing parameters	The integrated sensor and controller module accommodate a variety of external volume sensing systems. Additional payload can easily be added in the expansion bay and integrated with the package controller.
Accurate, high resolution physical and bio-optical measurements	The integrated physical and bio-optical sensor suite provides high quality, accurate measurement capabilities over a wide dynamic range, and thus provides a wealth of information on the biogeochemical processes.
Wide range of spatial and temporal resolution sensing capabilities	With profiling speeds ranging from 2 to 100 cm/s, the profiler is able to sample a wide range of vertical features from thin layers to bulk water masses. Sampling intervals are also configurable, with the minimum sampling interval limited to the time it takes to perform a single profile.
Multiple remote telemetry options	The profiler nominally operates in an autonomous mode (no telemetry option). A variety of telemetry options, including acoustic, spread spectrum radio frequency, and Iridium satellite modems, can be accommodated using the modular telemetry bay. With optional telemetry installed, the user selects when to telemeter data as well as the data compression algorithm to use.
Intelligent operational control	The controller logic receives multiple inputs from system components (winch, sensors, and controller) to manage sensor systems, power, profiling speeds, and data transmission. This allows for precise autonomous control of the system and for intelligent fault detection and recovery.

4D. Target application scenarios

Designing a system that encompasses all of these aspects is a formidable challenge. Constraining the system in terms of its functionality versus flexibility was the first step undertaken in this Phase I research. This step helped to define the application niche that the Mini AMP will fulfill. To ensure that the Mini AMP's capabilities will encompass a broad range of user's needs, we developed four generalized application scenarios; 1) Stealth mode, 2) Inshore, 3) General coastal, and 4) Offshore coastal. The vertical sensing needs for each application are described below. For each scenario, it is assumed that a desire measurement suite would include a CTD, chlorophyll fluorescence, downwelling irradiance, and single channel beam attenuation and backscattering.

1. *Stealth applications*: In some coastal applications, the ability to sample the water column without being detected is a high priority such as in covert military operations. In these

applications it is envisioned that the profiler would not breach the surface during any time besides deployment and recovery. Typical use scenarios are in high use shipping/fishing regions and in support of naval covert operations, where resolving the fine scale vertical structure of the optical properties is needed for predicting diver visibility. The ability to sample a wide range of vertical scales on an as needed basis would be desirable in this application.

2. *Inshore applications*: Inshore environments are classified as shallow water (< 30 m), such as bays, estuaries, or river mouths. These regions may be subject to strong tidal dynamics, are typically areas of high biological productivity, and experience a range of freshwater and oceanic inputs. High temporal variability scales from hourly to seasonal are typical of these environments. The envisioned users for these environments are the individual research scientist or regional resource manager. Additional sensing parameters such as colored dissolved organic matter fluorescence, dissolved oxygen and nutrients may be desired in these applications. High vertical and temporal scale resolution measurement capability would be required in these applications in order to resolve fine scale features such as thin layers.
3. *General coastal applications*: In the near coastal regime (water depths ranging from 30 to 70 m) processes such as buoyant plumes, wind driven upwelling, internal waves and thin layers strongly impact the vertical structure. These dynamic coastal regions experience high rates of biological production as well as large vertical and lateral fluxes of materials. The dominant temporal scales of variability range from hourly to seasonal, and are strongly impacted by the event (meso-scale) variability. Additional sensing parameters such as dissolved oxygen, nutrients, currents and waves may be desired in these applications. Potential users in these regimes may be the individual researcher, or as a part of a coastal observatory. In these productive regions, integrated anti-fouling devices would be of high importance to assure data quality and extend deployment duration. Adaptive sampling capabilities would be desired in these applications to capture event scale features.
4. *Offshore (shelf) coastal applications*: Outer continental shelf applications in water depths ranging from 70 to 100 m are targeted to the transition zone between the shelf and slope. These regions have complex dynamics between the prevailing coastal currents and large gyre circulation features which dominate the spatial variability. The physical dynamics in these regions are driven by the event to seasonal temporal scales and may be strongly impacted by wind driven upwelling forcing, boundary layer offshore transport, and bottom resuspensions. Long-term deployment durations up to 6 months may be required for these applications as a part of a large observatory network.

We foresee that these four different application scenarios would encompass ~90% of the envisioned usages of the Mini AMP system. These four different use scenarios are compared and contrasted in this report, demonstrating how the design of the Mini AMP allows for a multitude of configurations. Identification of the application matrix allowed for the definition of the overall system specification, and where the modularity and flexibility in system configuration and components needed to be incorporated.

4E. Primary embodiment specification list

The Mini AMP design is based on a bottom-anchored, autonomous, winch-driven profiler with integrated physical and bio-optical sensors for measuring critical in-water environmental parameters. Initial design specifications are listed below. These are based on our understanding of

the Naval and research needs and encompass the capabilities put forth in the Phase I proposal.

Deployment
- Up to 180 days deployment duration
- Operational in water depths of 3–100 m
- Maximum of 36 km distance traveled before servicing
- Suitable for currents up to 1 m s^{-1}
- Capable of deploying/recovering from a small vessel
- Bottom anchored with winch wire for attachment only

Operation
- Programmable for complete autonomous sampling
- Profiling speed range 2–100 cm s^{-1}
- Remote telemetry options – radio frequency, Iridium satellite, and acoustic modems
- Intelligent failure/problem diagnostics and recovery.
- Sampling acquisition control (ascent, descent, hold at depth)

Size and form factor
- Weight ~ 95 lbs in air (with batteries, winch and core sensor suite)
- ~20 pounds of buoyancy (adjustable from 10 up to 25 pounds)
- Length – 52 inches
- Able to sustain attitude throughout profile (within 10 degrees)
- Built-in anti-fouling protection

Power
- Primary 13 volt power supply for instrumentation and package controller
- Secondary 41 volt power supply for winch system
- Base 65 Ah capacity for each power supply
- Maximum current draw of profiler ~ 5 amps.

Core instrument suite
- CTD – SeaBird Electronics FastCat CTD, model # SBE49, with integrated pump
- BOSS
    - Single channel beam attenuation – Scattering and Attenuation Meter (SAM)
    - Fluorescence and single channel backscattering – WET Labs ECO style sensor
    - Spectral downwelling irradiance – Satlantic Inc. OCR507 series radiometer

Core Package and Data Controller
- Primary package controller with common interface to data control system
- Winch controller
- Ancillary measurements: Battery voltage/consumption, tilt/roll, time/date, cable tension

Winch System
- NEMA-23 type right angle motor with worm gear box
- Level wind with dynamic tensioning device
- DC power (operational voltage range of 12–48 V)
- Variable motor speed (1–5000 RPM), reversible

- Maximum motor torque ~ 250 oz. in. max.
- Keyed shaft for gear box and bale

Telemetry Options
- Two-way communications for data download and programming
- Options for acoustic, satellite modem and line of sight (RF) telemetry
- Intelligent and programmable telemetry

Data
- 512 MB on board storage capacity
- Raw data archiving
- Data merging based on time/depth
- Data processing to produce engineering and scientific units
- Data reduction and compression for remote transmission
- Standardized output protocol

Data Capture and Control
- GUI-based control software for system interfacing and data reception/transmission
- Backend receiving and decompression of data

5. Design Analyses

The design constraints of the Mini AMP specify that the profiling platform 1) be hydrodynamic with low drag, 2) maintain attitude within 10 degrees during upward profile, 3) profile at speeds ranging from 2–100 cm s^{-1}, 4) support operations in water depths ranging from 3 to 100 m, 5) operate in current speeds up to 1 m s^{-1}, and 6) be light weight (< 150 lbs in air) and easy to deploy. These initial specifications were used to study the feasibility of the profiler platform design.

In specifying the size and shape of the package we combined these requirements with several operational factors to express a design envelope of useful sizes and shapes. In fact many of the various requirements are interdependent. Size and drag, drag and buoyancy, buoyancy and required power, power and weight, weight and required buoyancy, and required buoyancy and size all interact in establishing the parameter space for the system design. In addition the dynamics of package flight during ascent and descent place requirements on the motive force and cycle duration for the pay-out and subsequent retrieval to dock of the package. Buoyancy and drag combine to establish total cable pay during ascent. Since the package will tend to re-align to the fall path during descent, the drag forces will lessen but the motor will have to overcome the full buoyancy of the package in order to retrieve it. These factors all couple into defining the power and duty cycle for the motor (thus required power capacity) for a given profile.

The first step in the design phase for the profiler platform was to select an equivalent profiler shape from which to estimate and model the hydrodynamic performance of the profiler. The most volumetrically efficient shape, a sphere, was first considered, however, it proved an inefficient usage of space to house the necessary electronics and instrument systems. Cylindrical shapes, while easy to build and integrate components within, proved very inefficient in terms of drag. This led us ultimately to a modified cross-sectional foil design that allows us to extend the weight distribution through a relatively long aspect ratio while maintaining reasonable hydrodynamic characteristics. With variable

diameters of package sections we can further separate and bias the buoyancy and ballast components. This form factor also lent itself well to a modular and efficient configuration of the system instrumentation and components. We thus chose to use a modified foil design for the initial design study for the Mini AMP profiler. With the choice of the shape of the profiler, we can estimate the static drag force exerted on the profiler perpendicular to its main axis (due to horizontal current flow) using:

$$F_D = \frac{1}{2} C_D A \rho v^2$$

$\mathbf{F_D}$ = Drag Force. Newtons
$\mathbf{C_D}$ = Drag Coefficient, Dimensionless
A = Cross-sectional area perpendicular to the flow, m^2
ρ = Density of the medium, kg/m^3
v = Velocity of the body relative to the medium, m/s

Assuming we are designing for a maximum 1 m s^{-1} horizontal current, our design variability relative to the above equation lies in defining the exposed surface area and the drag coefficient. We computed the drag force for a range of cross-sectional areas (0.1, 0.2, 0.3, 0.4, 0.5 m^2), using 3 different diameters (0.15, 0.23, 0.31 m), and various lengths. We assumed an average seawater density of 1025 kg/m^3. For each cross-sectional area, we computed the drag force for a range of drag coefficients (0.25 up to 0.75) and horizontal current velocities (0 to 1.0 m s^{-1}). The drag coefficient is dependent on the shape as well as the material of the object (specific surface roughness).

When pulling in the package, the winch motor power consumption is a function of drag and profiler buoyancy. The profiler must have enough positive buoyancy such that the platform is not tilted over horizontally under high horizontal current regimes. However, increasing positive buoyancy also translates into increased torque on the winch motor during profiling, which increases power consumption thereby decreasing the deployment duration.

Table 2 – Drag force (lbs) computed for a range of cross-sectional areas (cylinder) and drag coefficients in a 1 m s^{-1} horizontal current velocity.

	Drag coefficient				
Area (m^2)	**0.15**	**0.3**	**0.45**	**0.6**	**0.75**
0.15	2.592225	5.18445	7.776675	10.3689	12.96113
0.2	3.4563	6.9126	10.3689	13.8252	17.2815
0.3	5.18445	10.3689	15.55335	20.7378	25.92225
0.4	6.9126	13.8252	20.7378	27.6504	34.563
0.5	8.64075	17.2815	25.92225	34.563	43.20375
0.6	10.3689	20.7378	31.1067	41.4756	51.8445

Table 2 in effect defines the boundary conditions for the total package size and secondarily defines our desired buoyancy. Previous experience with the winch motors used on the ORCAS profilers, (QuickSilver Controls, Inc.; model number QCI-23H-5) has shown that current draw of the motor is a linear function of package weight (in water) up to about 25 pounds of force (figure 2). At weights greater than 25 pounds, current draw by the motor increases nonlinearly with increasing package weight. We thus defined the range of size and shape which we can determine operation.

This analysis helped set the upper bound on the target buoyancy needed for the profiler in this feasibility study. Once a servomotor has been selected for use on the Mini AMP, a similar analysis will be performed based on the selected motor specifications. Clearly, reducing the in water weight (or amount of positive buoyancy) of the platform reduces the power consumption of the winch motor. Keeping the positive buoyancy of the platform under 25 pounds will also reduce the required weight of the anchor used with the profiler.

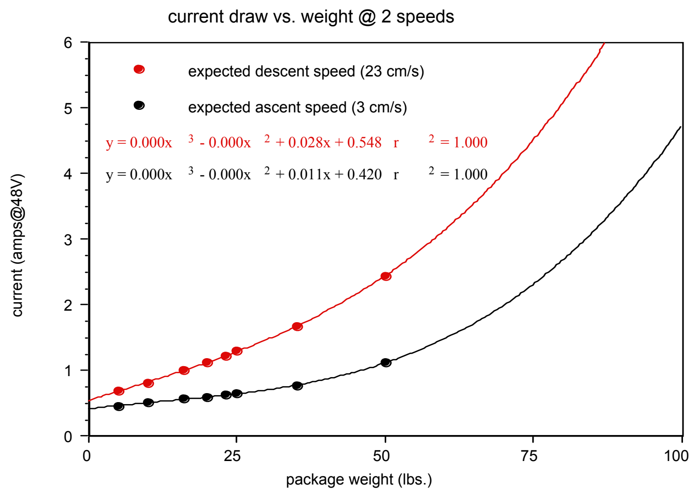

Figure 2– The expected current draw (at 48V) versus lifting weight for the QuickSilver Inc. motors used on the ORCAS profilers.

The most difficult parameter to estimate in this design analysis is the drag coefficient. Drag coefficients based on cylindrical shapes may range from 0.6 to values over 1.0 depending on the aspect ratio (length/diameter), the surface roughness and the flow regime (laminar to turbulent). By using a foil cross-sectional shape, we expect to reduce the drag coefficient.

As mentioned above, the desired maximum buoyancy of the package should be less than 25 pounds to conserve energy consumption by the winch motor. Table 2 shows that at a drag coefficient of 0.45, the drag force exceeds 25 pounds at cross-sectional areas greater than about 0.5 m^2 in 1 m s^{-1} horizontal currents. Recall that one of the design criteria is to make the Mini AMP compact and easy to deploy by two people. Based on these criteria, we selected a cross-sectional area of 0.3 m^2, roughly equivalent to a 1.3 m in length by 0.23 m in diameter cylindrical shape, as our design target, which should be reasonable to handle by two people.

Flight characteristics of the package through the water are substantially complicated by the fact the profiler is attached to a tensioning element – the winch line. This is of particular issue during the ascent phase and while holding at the surface. The winch attachment to the profiler will be biased toward the front of the package foil. This results in the condition that when the tension on the cable builds and the package begins to drift with the current it will tend to pull the package into the flow, thus optimizing the package drag characteristics. Separation of the ballast and buoyancy through a relatively long central axis tend to keep package upright during these conditions.

While our design analysis led us to what we view as a practical and efficient package embodiment,

a high priority in near term efforts is to validate design efforts through construction and testing of a scale model package shell with weight and tensioning proportionately distributed as we envision in our Phase I design. We propose to conduct this effort as part of our proposed Phase II development efforts (see section 10). Half and full scale models will be tested in a variety of current regimes and surface wave environments. The model's tilt, roll, orientation and wire tension will be measured, along with the current speed during ascent, descent and "hold" positioning of the profiler model. This will allow for a more accurate determination of the drag and hydrodynamic stability of the Mini AMP.

6. Mini AMP Primary Embodiment Design Details

In the following sections, we present design details for each of the components in the primary embodiment of the Mini AMP system. Each of the twelve system components are labeled in figure 3, with the estimated weight in air and water along with the righting moment of each component presented in Table 3. In the primary embodiment, the Mini AMP will be ~20 pounds net positively buoyant.

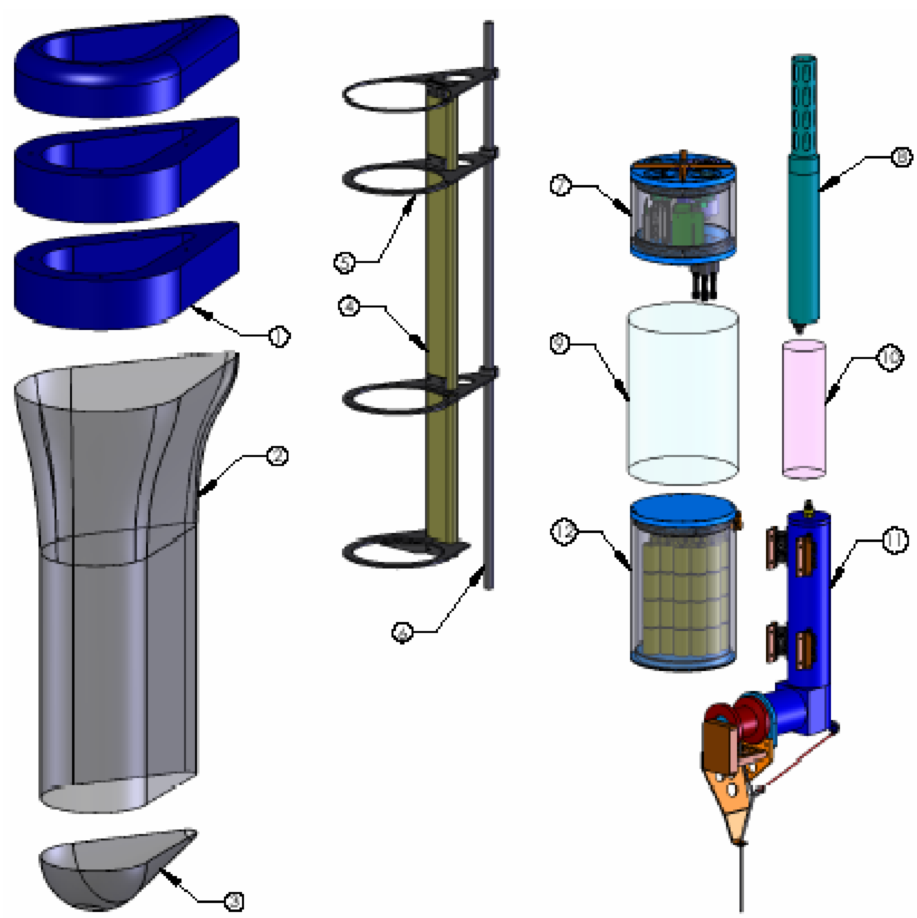

Figure 3–Exploded view of the primary embodiment of the Mini AMP system components. Labeled components indicate; 1) floatation rings, 2) outer skin, 3) end fairing, 4) strongback, 5) ribs, 6) rear spar, 7) bio-optical sensor system, 8) CTD, 9) expansion bay, 10) telemetry bay, 11) winch system, and 12) power module.

Table 3 - Weight and righting moment estimates of each of the Mini AMP system components shown in figure 3.

Figure 3 label #	Component	Weight in air (lbs)	Buoyancy in water (lbs)	Righting moment (in-lbs)
1	Foam float, rounded edges	3.80	11.89	481.46
1	Foam float, squared edges	4.06	12.63	561.90
1	Foam float, rounded edges	3.80	11.89	576.57
2,3	Polycarbonate skin & end fairing	4.99	-0.44	-11.63
4	Fiberglass strongback	2.69	-1.21	-32.07
5	Rib (typical)	0.93	-0.58	-6.05
5	Rib (typical)	0.93	-0.58	-14.26
5	Rib (typical)	0.93	-0.58	-25.15
5	Rib (bottom)	0.93	-0.58	-29.40
6	Rear spar	0.64	-0.40	-12.20
7	Bio-optical sensor system	12.00	3.35	157.38
8	SBE49 CTD in plastic housing	3.50	-1.00	-49.00
9	Expansion bay	0.00	0.00	0.00
10	Telemetry bay	0.00	0.00	0.00
11	Winch, level wind, and bale	19.00	-9.20	-95.68
11	Winch shock mounting system	1.0	-0.8	-13.5
11	Spectra® rope (150 m)	1.65	1.65	0.00
12	Power module (with batteries)	33.55	-6.10	-106.67
	TOTAL	**94.66**	**20.67**	**1367.03**

6A. Platform structural design

The primary structural components of the Mini AMP include a center core strongback, four separation and mounting ribs, and a rear spar (figure 4). All three components work in concert to provide the rigid framework and the foil form factor for the Mini AMP. The purpose of the strongback is to provide rigid support along the vertical axis of the profiler and to provide a mounting surface for the ribs. The strongback will be composed of a light weight, strong structural fiberglass material which is easy to machine and resistant to corrosion. The shape of the rib members are designed to mimic an airfoil to give the body of the profiler a hydrodynamic shape. The aluminum ribs are 9” in diameter and 15.75” in length with mounting tabs to connect to the strongback. The ribs separate the modular bays and provide a mounting surface for the Mini AMP system components. A rear aluminum spar connects the upper three ribs, providing additional rigidity to the frame. The lower rib is not attached to the rear spar in order to accommodate the winch system. The rear spar is slightly extended above the profiler’s top surface to provide a hand hold during deployment and recovery.

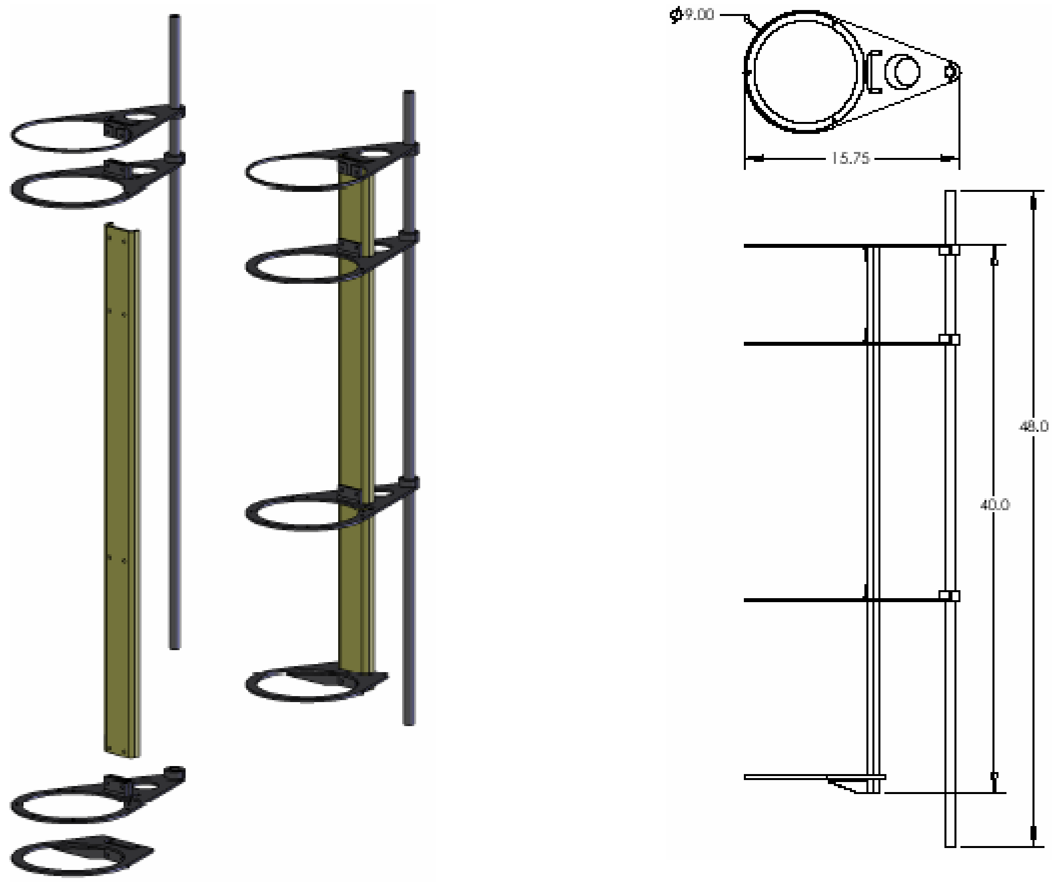

Figure 4– Schematic drawing of the Mini AMP structural framework. The main strongback is made of structural grade fiberglass. The aluminum ribs are mounted to strongback using the welded tabs. The hollow rear spar is made of aluminum and provides additional strength along the vertical axis of the frame.

6B. Outer Skin and Floatation

The outer shell provides the Mini AMP with a smooth outer surface and a foil shape (figure 3). The tapered end fairing shell protects the winch system components and reduces the package drag during the profiler's descent. Both components will be made of a durable plastic, such as polycarbonate or acrylic and formed by blow-molding. The floatation system is composed of 3 sections of hydrostatic-pressure resistant foam (300 psi rated) glued together. There are several companies that manufacture this type of foam and can machine these parts to our specifications. By using a layer ring floatation system the net buoyancy of Mini AMP can be easily adjusted by simply varying the thickness of each layer, thus accommodating variations in the payload weight.

6C. Bio-optical sensor system and CTD

In designing the core instrument package our goal was to strike a balance between component modularity and integration. As a result the core package combines a Seabird "FastCat" SBE 49 CTD with and integrated bio-optical sensor system (BOSS) that integrates a beam attenuation measurement (open volume) with backscattering, and fluorescence in a single housing (figure 5). The optical suite of instrumentation included in the BOSS is based on commercially available and developing technology. The integrated fluorescence and scattering optical block and electronics used on our current line of ECO style sensors (WET Labs FLNTU) which have already been integrated with other platforms such AUV's and gliders. The spectral downwelling irradiance

sensor integrated with the BOSS will use the optical block and electronic board set of Satlantic Inc.'s OCR 507 sensor. A Scattering-Attenuation Meter (SAM) will be integrated with the BOSS system to provide measurements of the beam attenuation coefficient at a single wavelength. The SAM is currently in Phase II development under a separate ONR SBIR by Dr. Michael Twardowski of WET Labs. The SAM derives beam attenuation, by making two measurements of backscattering at the same angle but over different pathlengths. The SAM employs a 650 nm laser-diode drawing only 0.07 amps at 12 V. The SAM optical blocks and electronics form factors are amenable to integration with BOSS, although testing will be required to ensure proper alignment and ambient light rejection. The SAM has been integrated with and deployed on a variety of sampling platforms, including vertical profilers, towed vehicles, and autonomous glider vehicles.

In addition to the bio-optical sensors, the BOSS also holds the central package and instrument controller as well as the winch controller microprocessors (see description in Electronics Design section below). Serial, analog and switched device connector inputs are provided on the end flange of the BOSS pressure housing to accommodate future sensor integration. The CTD is incorporated as a separate sensor set that feeds data through the bio-optical sensor system end flange connector. The BOSS will also have a fully integrated anti-fouling solution based on our bio-wiper technology. A narrow diameter pressure housing that contains a small motor device will be integrated into the center of the BOSS, thus effectively isolating the motor from the BOSS electronics. An X-shaped wiper mechanism attached to the external motor shaft will activate at the start of each upcast, clearing the sensing surfaces of each of the optical faces of debris. This provides for one integrated anti-fouling solution for all optical sensors based on proven technology.

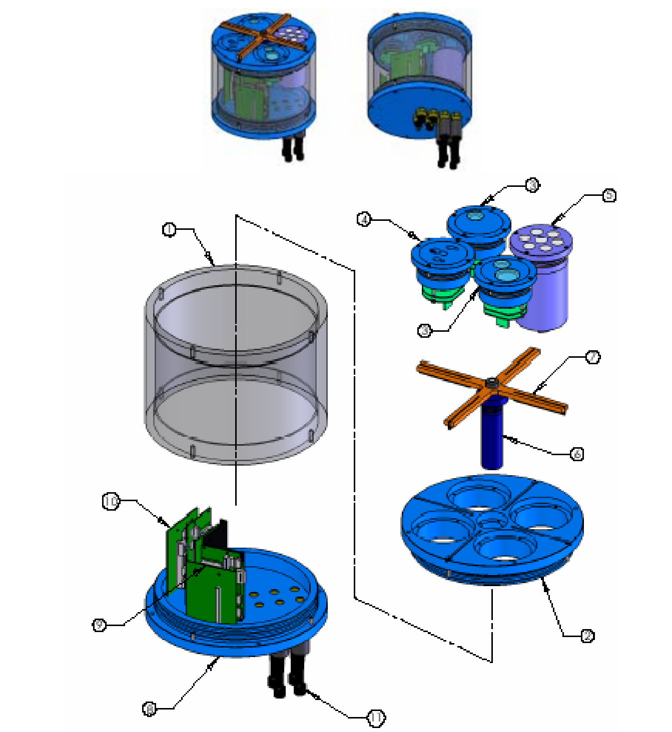

Figure 5– The integrated bio-optical sensor system (BOSS) in side view (top panel) and in an exploded view (bottom panel). Labeled components are 1) pressure housing, 2) top end flange with holes for optical instrumentation, 3) SAM optical heads and board sets, 4) ECO style optical head with fluorescence and backscattering sensors, 5) Satlantic OCR507 irradiance sensor optical block, 6) wiper motor housing in pressure housing, 7) anti-fouling bio-wiper, 8) bottom end flange, 9) winch motor controller electronics, 10) primary package controller electronics, and 11) BOSS bulkhead connectors.

6D. Winch system

The winch will incorporate a NEMA-23 type motor with a worm gear for right angle translation and a custom bale level winder. Initial specifications, torque ratings, and power consumption estimates used in the design analysis of the Mini AMP were drawn from our experience with the

ORCAS prototype winches manufactured by QuickSilver Controls, Inc. While the servomotor we choose may differ from the ORCAS profiler, investigations thus far have shown that motor size-efficiency factors similar or worse among other identified options. In Phase II, we will select a servomotor to use for the Mini AMP based on the following specifications:

- NEMA standard frame (size 23 preferred)
- Built-in or capable of right angle translation using worm gear
- Can be submerged (i.e. VEP or similar sealing process)
- DC power (12 –48 V range), maximum current < 4.0 amps
- Variable motor speed (1-5000 RPM), reversible
- Motor torque ~ 350 oz-in maximum
- Keyed shaft for gear box and brake adaptation
- Maximum size dimensions: 6" x 3", weight should be < 10 lbs.

Designed for *Spectra®* rope, the winch will incorporate spring-loaded dynamic tensioning between the level wind and the cable fairlead. This will allow temporary slackening of the cable without it jumping the bale and getting bound. The tensioning of the cable is achieved by a spring loaded cable assembly shown in figure 6. Incorporating a grab pulley in the center section, the tensioning system also takes up snap energy at the sea surface should the package be subjected to sudden changes of effective surface height due to wave action. The winch is mounted to the fiberglass strongback support member using stainless steel wire rope shock mounts. This mounting system helps to isolate vibration and shock energy translation onto the profiler's frame induced by cable drag and surface wave action.

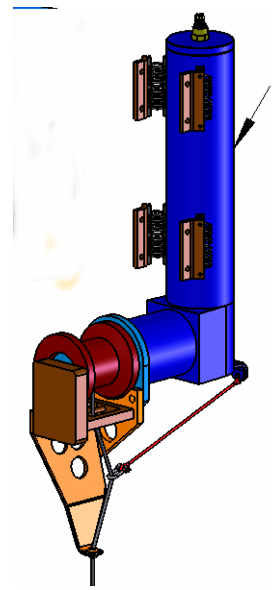

Figure 6 - Winch system with dynamic wire tensioning device and shock mounts.

The primary winch shaft incorporates a double seal as shown in Figure 7. This seal design evolved with use and experiences with the ORCAS seal. Protection of the winch motor is further assured through attachment of a fully oil filled sealed worm gear box. The gear box offers three advantages. It provides a compact mechanical design. It mechanically decouples tensioning from the cable from the motor shaft. It removes the need for a brake on the motor.

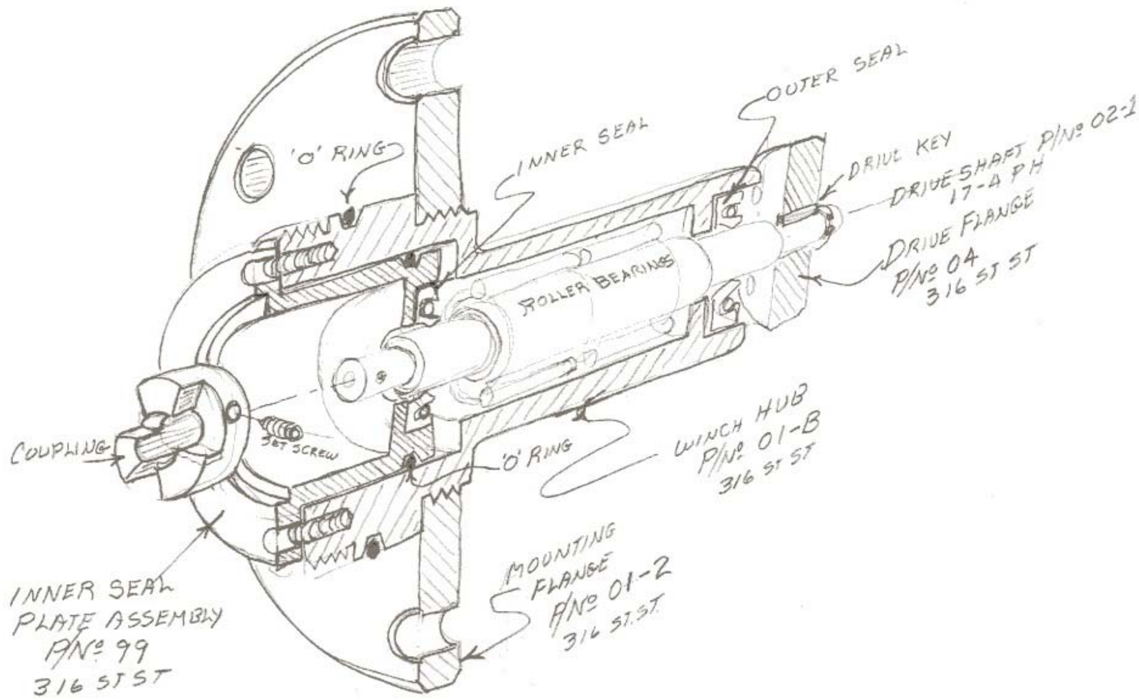

Figure 7 – Schematic of the winch shaft, housing, end flange and bale coupling.

6E. Power module and estimated power budget

A single battery unit providing two voltage levels will provide power to the profiler. A low voltage (nominal 13 volts) cell will provide 65 amp-hrs operational capacity for the package controllers, telemetry unit, and sensors. A 41 volt 65 amp-hr module will provide power for the winch motor. The single unit design provides a simple swap-out for the power unit using modular 13 volt, 15 amp-hr 4 D cell lithium-ion stacks (figure 8). The battery pack, along with the winch also serves as primary ballast for the profiler. An estimated power budget for the primary embodiment of Mini AMP system is presented in table 4.

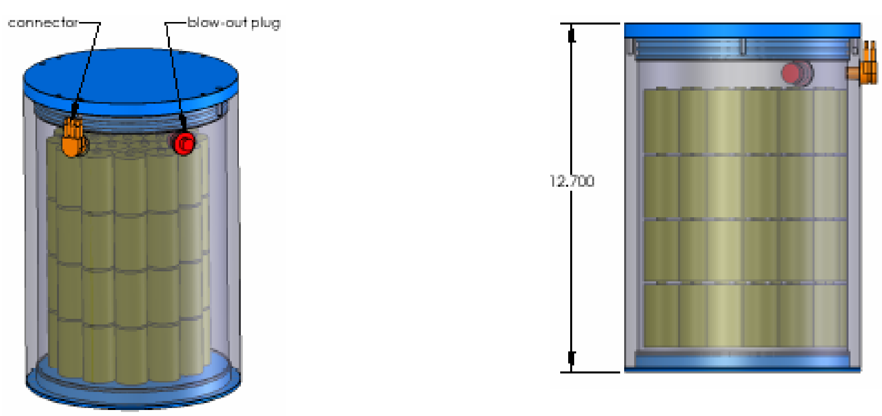

Figure 8– Three dimensional view of the power module with pressure housing, electrical connector and pressure relief valve (top two panels). The lithium ion battery stacks are also shown.

Table 4 - Primary embodiment Mini AMP estimated power budget

Assumptions:	
Number of casts (ascent + descent = 1 cast)	180
Length of wire traversed, ascent or descent (m)	150
Ascent rate (m/s)	0.20
Descent rate (m/s)	0.50
Ascent time (hrs)	0.21
Descent time (hrs)	0.08
Sleep time (hrs)	0.63
Total distance traveled (m)	54000

Component	**Current draw (A)**	**Single profile current consumption (A-hrs)**	**Total deployment current consumption (A-hrs)**
12 volt systems			
BOSS - SAM	0.08	0.02	3.00
BOSS - FLNTU	0.08	0.02	3.00
BOSS - OCR507	0.04	0.01	1.50
SBE49 - CTD	0.31	0.06	11.63
Diagnostics (ascent)	0.20	0.04	7.50
Diagnostics (descent)	0.10	0.03	5.25
Package Controller	0.10	0.03	5.25
Winch Controller	0.10	0.04	6.75
Sleep	0.00	0.00	0.02
TOTAL	**1.01**	**0.24**	**43.90**
48 volt systems			
Winch (ascent)	0.80	0.17	30.00
Winch (descent)	1.50	0.13	22.50
TOTAL	**2.30**	**0.29**	**52.50**

6F. Expansion bay

Four switched power, 8 analog, and 5 serial sockets will be provided for the expansion bay which will offer 827 cubic inches of space for other instruments. This large volume should accommodate a variety of oceanographic sensors with minimal alteration to the Mini AMP framework. We expect that incorporation of sensors requiring pumped flow, such as dissolved oxygen, absorption, nutrient sensor, will be highly desired by a variety of users of the Mini AMP.

6G. Telemetry bay

Although the primary embodiment of the Mini AMP does not include a telemetry module, ample space is provided in the center rear section for possible integration (figure 3). The telemetry bay is designed to handle any one of the three envisioned telemetry options: acoustic modems; high-speed spread spectrum radio frequency (RF) modems such as Freewave system; and an Iridium

satellite modem. An antenna shaft (secured to the hollow rear spar) is supplied to couple the RF and Iridium options to the surface when used. In order to focus on the design analysis of the critical components needed by the Mini AMP, we chose not to specify one type of remote telemetry system for integration. The efforts of this Phase I design analyses however did include considerations for accommodating a telemetry system in terms of form factor, space, power, package controller interfacing and data transmission. As the choice of the type of remote telemetry (RF, acoustic, satellite) will be application specific (see Application scenario matrix section) the Mini AMP design must accommodate its integration. Our proposed implementation plan for Phase II research will include integration of each of these telemetry options with the Mini AMP system.

7. Electronic systems design

A single Persistor CF-2 based embedded computer module will serve as the primary controller for the entire package. We have been using the Persistor CF miniature computer modules as the core data acquisition and instrument control unit for many of our high end products, such as the WET Labs DH-4 and ac-s systems. The primary controller will sequence power to the sensors and winch, prescribe winch operation and end conditions, collect, store and telemeter data from individual environmental and diagnostic sensors, and communicate as required with a host system in order to provide system configuration parameters. The package controller contains substantial input/output capabilities to facilitate system operation. Table 5 outlines dedicated system channels for the Mini AMP. These include a total of nine serial channels, eight analog channels, four addressable switches, as well as an internal SBI bus for modular integration of controller components.

Table 5 – Package Controller I/O

Host Primary Communications	Primary serial com port
Telemetry Communication	UART Ch 1
Winch Controller Communication	UART Ch 2
Sensor Communication	UART Ch 3 - Ch -8
System Diagnostic Measurements	ADC Ch 1 - Ch – 8

7A. Package Controller

The package controller will be integrated in the BOSS module. It will consists of a

- Persistor CF-2 microcontroller unit (figure 9).
- Two 4-channel buffered UART boards
- A custom IO board containing high current switches for the winch and sensor operation, and a general purpose 12 bit analog to digital converter with 8 multiplexed inputs
- 512 MB flash memory card.
- Watchdog circuitry to monitor the package controller status and initiate a hardware interrupt should problems occur.

The controller will serve as the master sequence driver for the profiler. Based upon configuration information preset before deployment or during a surface communication sequence with a remote host, the controller will determine the time for deployment, switch on and initialize system sensors and the winch, provide configuration information to the winch controller and initialize winch operation, monitor and log environmental sensor input during ascent, telemeter data to a remote host as designated, engage the winch controller to return the system to dock, and return the system to a quiescent state upon cycle completion. Between cycles the controller remains at a low power state (approx 50 micro-amps) conserving power. All other sensors and the winch remain off during

this time.

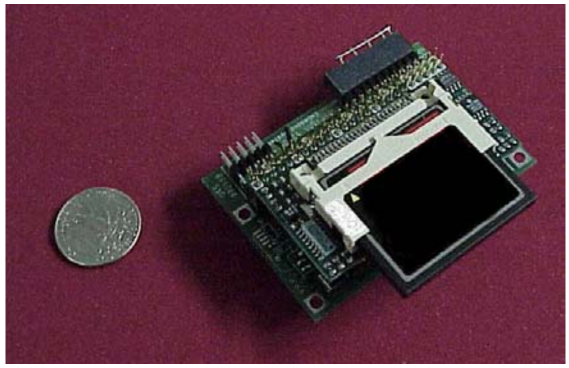

Figure 9– Picture of the Persistor Inc. microprocessor board set with on board flash card.

7B. Winch control module

Winch operations are managed by a separate dedicated controller that receives configuration information from the host via the package controller. The winch controller monitors cable pay data from the winch, pressure from the CTD, and tilt and roll data to determine current winch status. The winch controller will provide diagnostics information to the package controller for system control and sampling.

Both cable pay and depth from the primary CTD are used in determining winch position (Note that the CTD data is fed separately to the package controller for environmental data input). Cable pay represents the geometric sum lateral and vertical displacement of the package. Depth represents distance from the water surface. Dynamic positioning of the profiler is determined by both of these parameters, depending upon the phase operation.

- *Initiate profile*—Depth sensor and cable position are both determined to define "home position." Winch begins release of the cable.
- *Profiling*—Cable pay defines rate of package ascent. Depth is monitored to determine position relative to surface.
- *Stop ascent*—Stop of vertical ascent can occur either when maximum cable is paid from winch or when minimum set depth is reached.
- *Assess surface*—Once the minimum set depth is reached, pressure measurements are recorded over a user-defined interval to determine an approximation of surface level activity. This information provides both amplitude and periodicity and allows the package to determine whether it is safe to surface and transmit data. It also can determine whether currents are sufficiently strong to pull the package under without further release of winch cable.
- *Hold surface level*—The package can be instructed to hold (within it's ability to respond) near the surface in order to transmit data or wait for retrieval.

8. Operation

The design and specifications for the Mini AMP profiler couple with standard operation procedures to define the package's behavior in the water. The Mini AMP operates within 6 primary operational domains:

1. Primary deployment;

2. Docking;
3. Profile ascent;
4. Surface holding;
5. Profile descent;
6. Retrieval.

Primary Deployment—We plan to make the Mini AMP deployable by two people from small vessels in most all conditions. The Mini AMP will be provided with a simple two wheel transport cart that will allow easy transport on and off the deployment vessel. The cart will also double as a launching platform for the profiler. Numerous deployment possibilities exist and learning best practices will be a major component in the Phase 2 work plan. In most general terms there exist two modes of deployment: controlled spool-out; and full-package immersion with auto spool-out as the Mini AMP and its anchor descend through the water column. In effect, the latter scenario involves pitching the package and anchor into the water and allowing the winch to unspool the anchor enough to assure that the profiler frame and the bottom dead-weight don't collide upon descent and landing at the bottom. This mode would carry distinct advantages in situations in which prolonged exposure of the surface vessel during the deployment sequence might create an unacceptable hazard. While this condition will be required at times, the more preferable package release will involve spooling the anchor system into the water prior to package release. This basic deployment sequence would entail: 1. Positioning and locking the cart and package such that the bottom of the cart has direct clearance to the water (assume less than 2 meter height above the water surface). 2. Attaching the bottom weight and drag anchor to spindle at the end winch cable. 3. Activating the winch (note manual control mode for winch) to begin unspooling the weight and anchor in the water. 4. Once the anchor and cable are deployed, the vessel is drawn forward so a light tension remains on the cable, releasing the package.

Once in the water the system would, depending upon it's programmed deployment script, either wait at the surface to establish communications or just descend to it's docking point. An initial profile would then ensue, with the package coming completely to the surface. This would allow for visual inspection of the operation.

Docking—The docking state describes the bottom dwelling quiescent condition of the profiler. Depending upon telemetry options the sensors and the winch are turned off during this phase of operation. The package controller exists in a low-power sleep state, awaiting a timer wake-up command. The package could also respond to external events to wake if directly coupled to a serial controlled host or if coupled with an acoustic modem.

Ascent—The platform is designed to vertically profile over a range of user selectable speeds in current speeds up to 1 m s^{-1}. The package controller, normally in sleep mode, activates the profiling sequence at the user defined intervals, powering the winch system and instrumentation suite. Environmental instrumentation is powered during the ascent cast only, allowing for undisturbed measurement of the oceanic properties. At the top of the profile, the package controller turns off the bio-optical instrument suite, but leaves on the CTD for use with the winch controller. It then descends approximately 1–2 meters to hold and assess surface conditions.

Rate of ascent will be controlled by monitoring both the amount of cabled paid by the winch and

by monitoring the pressure measurement of the CTD. The package controller must adjust the winch speed such that the desired vertical rate of ascent is maintained. In high current regimes, significant lateral displacement of the package may occur. As the current profile may change speed and direction, the controller must have the ability to adjust to this variability. The computation of the profiler vertical ascent rate will be done using running average of the CTD's pressure data. The vertical rate of change (based on the pressure data) is computed over a preconfigured time interval, and the average ascent rate is computed. The motor speed is then adjusted to match the desired ascent speed. The horizontal displacement distance is also estimated and recorded. In certain applications the user may optionally determine ascent rate simply by cable position alone. In this mode of operation the pressure sensor is used only to determine end conditions.

***Surface holding*—**If the profiler is programmed to telemeter data at the surface it will require establishing a holding state to allow time to establish communications and offload data. The package will first look at the depth data variance from it's interim holding position to estimate surface conditions. If conditions exceed normal operating conditions then the package will begin a descent cycle. Otherwise the package will ascend high enough to breech the antenna into the atmosphere. The winch controller will monitor depth and cable angle data to determine if the package is getting pulled under by the currents. Meanwhile it will attempt for a pre-programmed time to establish communications, offload data, and retrieve programming instructions.

***Descent*—**During the descent profile, the winch motor is operated at an increased speed to lower the platform back to its resting state near the bottom of the water column. The package controller then powers down the winch motor, and enters a low power sleep mode. All collected data is stored on an on board flashcard for later retrieval or remote transmission. Although the descent operation ultimately depends upon the cable-pay, the CTD remains on during the descent cycle to assess effective depth.

Recovery—Basic recovery would entail having the package reel out all the cable. It then goes into a holding pattern on the surface. Once the retrieval vessel pulls aside the package it is then lifted on board and locked to the transport cart. The boat is then used to "break" the anchor from the bottom. Placed into manual operation with an external battery, the package winch then lifts the anchor from the bottom.

Normal operation will require monitoring of multiple parameters in novel ways in order to gain the required information to make effective decisions. These measurements also provide unique environmental data. Cable pay coupled with depth information and knowledge of the profiler's drag characteristics will provide useful current information. Near-surface sampling of the depth over time will also provide a wave-height spectrum. These parameters will duly be recorded with the rest of the environmental data.

9. Application scenario matrix

During design discussions related to the Mini AMP it became apparent that there were many potential applications for the system and no single implementation of the package proved optimal for all conditions of use. Location in which the package is to be used, the frequency and duration of use, availability to service, exposure vulnerability and the water environmental conditions all play roles in constraining the package and ultimately influence design decisions for the profiler.

Our ultimate commercial goal with the Mini AMP is to build as broad an application niche as possible. With each use scenario comes trade-offs in functionality and operation. Thus, designing some flexibility into the configuration becomes imperative. Based on the four target application scenarios (stealth, inshore, general coastal, and offshore coastal) described in section 4D, we developed a laundry list of desired vertical profiler capabilities. Each profiler capability was ranked based on its relative importance to the operational needs of each application scenario (Table 6). This matrix helped to define the necessary versus desired profiler capabilities for each of our target applications.

Table 6 – Application scenario matrix of desired profiler capabilities. Ranking of desired needs are based on the target application scenarios outlined in section 4D. Rankings are 2 = high priority capability, 1 = desired capability, but not critical to operations, and 0 = lower priority.

	Application scenario			
Profiler capability	*Stealth*	*Inshore*	*General coastal*	*Offshore coastal*
Self-contained, single component system	2	2	1	0
No surface expression required	2	1	0	0
Easy to deploy from small boat	2	2	1	0
Integrated CTD measurement suite	2	2	2	2
Integrated bio-optical measurement suite	2	2	2	1
Integrated current measurements	1	0	2	2
Additional payload/sensor capacity	1	2	1	1
Integrated sensor anti-fouling devices	1	2	2	2
Long-term deployment capacity (6 months)	1	1	2	2
Programmable profiling speeds	1	2	2	1
Adaptive sampling capability	2	2	1	0
Multiple telemetry options	1	2	1	0
Intelligent data transmission / compression	0	0	2	2
Performance reliability	2	2	2	2
Cabled observatory ready	0	0	1	1

Current commercially available vertical profiling systems include the McLane Research Laboratories, Inc. Moored Profiler (MMP), Brooke Ocean Technology LTD SeaHorse™, and the Autonomous Vertical Profiling System (AVPS) from InterOcean. The MMP uses an on board winch to drive the profiler up and down a taut mooring wire. The SeaHorse™ uses a combination of wave action to propel the profiler down a taut mooring wire and buoyancy to ascend through the water column. Both of these systems require a permanent mooring cable and a surface or subsurface float. From a military point of view, a major drawback of these systems is the fixed presence of the mooring wire and a surface or sub-surface buoy. Surface expression is also a concern in coastal research applications because it may invite vandalism. These systems have limited capability to adjust the profiling speed, and are not able to resolve a broad range of vertical features. Telemetry options supported by each system are also highly limited.

The AVPS is a 4 component profiling system consisting of a subsurface data buoy (telemetry and buoyancy), a data acquisition system (instrumentation and controls), and a seafloor underwater

winch profiling system. The AVPS incorporates a bottom-mounted winch with a slip ring for transfer of power and data to and from the sensor package through an electro-optical-mechanical wire. This design makes the package vulnerable to several hazards, including rotation which ultimately applies excess torsional stress on the cable. Importantly, bottom-mounted winch profiling systems are highly susceptible to surface wave height which alternatively produced conditions of sudden slack and tension in the cable. These systems are also large and heavy, power demanding, with individual platforms for the winch and data system which increases the complexity of the deployment and recovery of these systems.

We believe that the innovations of the Mini AMP system will fill a unique niche in ocean research that will service a broad spectrum of coastal oceanographic research and military needs. The compact self-contained design, multi-parameter measurement capability, long-term deployment capacity, and flexible operational controls of the Mini AMP will provide a system that is unsurpassed in comparison to current commercially available profiling systems for the coastal environment. A similar matrix to that shown in Table 6 was developed to compare the proposed capabilities of the Mini AMP versus three other commercially available profilers (Table 7). A simple ranking system was used denote if the desired capability is present in each profiler. For the 3 commercially available profilers shown in Table 7, all data was taken from currently available documentation listed on the manufacturer's web sites.

Table 7 – Comparison of current autonomous moored profiling capabilities with the proposed Mini AMP system. Current commercially available vertical profiling systems include the McLane Research Laboratories, Inc. Moored Profiler (MMP), Brooke Ocean Technology LTD SeaHorse™, and the Autonomous Vertical Profiling System (AVPS) from InterOcean systems. Capabilities are based on published specifications and the proposed Mini AMP design. 4D. A 1 indicates capability present, 0 denotes unknown or unproven capability, and -1 indicates that the capability is absent.

Profiler capability	**Profiler**			
	Mini AMP	*MMP*	*SeaHorse*	*AVPS*
Self-contained, single component system	1	-1	-1	-1
No surface expression required	1	1	-1	1
Easy to deploy from small boat	1	-1	1	-1
Integrated CTD measurement suite	1	1	1	1
Integrated bio-optical measurement suite	1	-1	1	-1
Integrated current measurements	-1	1	-1	1
Additional payload/sensor capacity	1	1	1	1
Integrated sensor anti-fouling devices	1	-1	1	-1
Long-term deployment capacity (6 months)	1	1	0	1
Programmable profiling speeds	1	-1	-1	1
Adaptive sampling capability	1	-1	-1	1
Multiple telemetry options	1	-1	-1	1
Intelligent data transmission / compression	1	-1	-1	1
Performance reliability	0	1	1	0
Cabled observatory ready	-1	-1	-1	1

Using the data provided in Tables 6 and 7, we generated a simple profiler suitability matrix to rank

the functionality of each profiler for the 4 target applications (stealth, inshore, general coastal and offshore coastal). For each application, the matrix of desired capabilities (Table 6, column data) was multiplied by each profilers design functionality (Table 7, column data), and then summed to produce a suitability ranking, where higher numbers indicate that the profiler has a larger proportion of high priority capabilities for that particular application (Table 8). Although data for the Mini AMP is based purely on our preliminary designs, the data in table 8 indicate that the Mini AMP's proposed capabilities will service the needs of the targeted applications. In fact, in comparison with the 3 other commercially available autonomous moored profilers, the Mini AMP ranks the highest in suitability across all applications, with the exception of the offshore coastal application where the Mini AMP and InterOcean AVPS are equally suited.

While the above analysis is skewed towards our projected Mini AMP, as the need for developing the Mini AMP was based on our initial design constraints, it does demonstrate that the design put forth in this Phase I effort will produce a system that will have a broad range of coastal applications. Our ultimate goal is to develop a sound technological base for the Mini AMP system which will lead to a successful development of a commercial product line. The Mini AMP capabilities will allow WET Labs' researchers and customers to apply profilers to a variety of applications. These applications will in-turn lead to further derivative embodiments. Thus the Mini AMP effort not only sets the stage for a variety of future scientific investigations and naval operations, but also provides a base from which to develop new product lines that play off the core technologies. A longer view holds that as our core technologies improve with increasing use and broadening applications, subsequent improvements in capabilities are bound to emerge. In particular, we foresee the profilers 5 years from now, smaller, possessing more sensors, and consuming less power. These improvements will make the profilers ever more powerful and broadly used with an expanding application base.

Table 8 – Profiler suitability for each of the four application scenarios outlined in section 4D. A higher score indicates an increased suitability for use in a particular environment.

Application scenario	**Profiler**			
	Mini AMP	*MMP*	*SeaHorse*	*AVPS*
Stealth	16	-2	1	4
Inshore	20	-6	3	4
General coastal	14	-4	0	8
Offshore coastal	8	2	2	8

10. Preliminary implementation work plan

In assessing the overall design feasibility of the Mini AMP the question arises, "Do the efforts entailed in completing the envisioned embodiment fall within the scope of a Phase 2 effort?" In review of the specifications and design analysis we determined a set of tasks that provide a logical path for efforts to proceed. The primary goal of these tasks would be to implement and validate three profilers. Two of these units would see extensive field use by scientists within the community while another would be kept as an in-house test and development platform. Within this context we developed a preliminary development plan that will provide the first prototype platform

within six months. Once this unit is developed, testing and operational capability development will become an ongoing aspect of the project. This part of the project would entail numerous deployments coupled with iterations of system modifications in order to develop operational capabilities. We view this period of extensive trials as critical to overall success of the project in that they will help us develop the desired range and capacity for the prototype. Ideally this testing could be coordinated with ongoing Naval efforts such as the Layers Organization. In general tasks are divided between primary implementation and developing operational capacity. Option efforts associated with Phase 2 are all so outlined.

1. *Develop and test scale model of primary platform*—The design concept embodied in this design presents interesting design challenges. We need a platform design in which drag forces are minimized in order to reduce drift on ascent and minimize total required buoyancy for the package. We also want a stable platform when the package is at the surface. Depending upon the specific state of operation (resting at dock, ascent, holding at surface, descent) the profiler will exhibit unique behavior. By building inexpensive half and full scale simple platform models and by testing in various conditions we can optimize this aspect of operation before we make substantial investment in a final frame and shell.
2. *Winch development and testing.* A reliable winch is the keystone component in the Mini AMP design. Winch design, fabrication, and testing will thus prove a first item priority in the project arc. Development includes integration of the motor, controller gearbox, and the primary bale into a single assembly. Design efforts will also include development of the level winder and tensioning system for the bale.
3. *Controller development*. Existing WET Labs' package and winch controller architecture will be upgraded for latest version of CPU board. Firmware development will focus upon broader use of diagnostics to determine and act upon system status. This applies to profile and retrieval conditions as well as end conditions and system exceptions.
4. *Host station development.* An intuitive GUI-based host package will get developed for configuration of and data gathering from the profilers.
5. *BOSS implementation and testing*. The integrated bio-optical sensor suite and package controller will be developed to meet specific core acquisition requirements of the Mini AMP.
6. *Data handling*. While primary implementation efforts will not emphasize telemetry options the advantages of providing some basic data compression prove obvious in almost any scenario. We will thus develop and implement data compression as a standard component of the profiler capabilities.
7. *Primary package 1 fabrication.* Once the above elements are defined we will implement the first system and begin tests.
8. *Platform operations tests—in-shore operations development.* In general we will address operations development in an evolutionary manner we will first focus on inner coastal waters and eventually carry our capabilities to shelf operations. In each case we will define specific benchmarks to define levels of system operation. With regard to this our first goal will be to develop operational capabilities for inner coastal waters (to 30 meters). Tests will focus on all aspects of deployment including deployment, cycling and retrieval.
9. *Platform implementation tests—duration and remote telemetry.* Early testing will also insure that the profilers can operate over prescribed durations of roughly 36 kilometers. In these tests we will develop specific response scenarios for systems depleted of power. This step will also require the integration of remote telemetry to monitor the profilers operation

in real time. A spread spectrum radio frequency telemetry system (Freewave) will be integrated with the profiler for this phase of the project.

10. *Design review.* Pending completion of the first round of tests we will conduct a design review to determine what design modifications are required prior to and concurrent with fabrication of the next two packages.
11. *Platforms 2 & 3 construction*. An additional two profiler prototypes will be constructed at this stage after modifications based on the design review have been completed. This phase will also include integration of an Iridium satellite telemetry system with the Mini AMP.
12. *Platform operations tests—General coastal testing.* Coastal deployments will entail use of the profilers in more exposed deeper waters (to 50 meters). As with inner and near-coastal deployments all parts of the deployment cycle must be developed and tested.
13. *Platform operations tests—Special scenario development.* While developing and proving capabilities of the profiler in a variety of standard operating conditions is a required task, the reality of our mission of making the Mini AMP operational requires understanding how to operate the package in non-standard scenarios. Operation in high seas, recovery from loss of communications, and change of geographical position, are all potential hazards that the profiler might encounter. We will focus effort on response to and recovery from these and other abnormal conditions.
14. *Platform operations tests—Shelf tests.* Our final phase of testing will entail deploying the profilers in 50-100 meter waters.

We also plan on proposing at least four Phase II development options (~$150K each). These options include 1) the integration of chemical sensing systems (both passive and wet-chemistry) with the Mini AMP system in the expansion bay, 2) the development of a pumped flow through environmental sensing module that would include spectral optical properties, dissolved oxygen, and pH for use in the Mini AMP expansion bay, 3) development and field testing of a network of Mini AMP systems, 4) integration of a passive acoustic device for ship avoidance, monitoring and recovery surfacing, and 5) development of a trawl resistant bottom mounted profiler housing module.

11. Conclusions

In this draft technical report we have provided results of initial analyses into the design of a light-weight, autonomous, modular, bottom-up vertical profiling system named Mini AMP. The results of these analyses were used to produce a set of mechanical and electrical specifications and designs for the Mini AMP that emphasizes operational reliability, ease of use, and configuration flexibility. We believe that the results of this Phase I research effort demonstrate the feasibility of developing a Mini AMP system, positioning us to take this project to Phase II. We presented a development pathway that will lead to the successful implementation and construction of the Mini AMP system.

Our goal is to develop a multi-parameter, reliable, long-term vertical profiling capability that promise to significantly advance observational science and monitoring of coastal waters. We believe that the capabilities of the Mini AMP design represent a significant innovation in sampling technology above and beyond the capabilities currently available from existing profiling platforms. The Mini AMP system will provide a reliable, easy to maintain, and rapidly deployable/recoverable solution to obtaining long term, high vertical resolution profiles of important physical and bio-optical properties

in coastal regions.

Our ultimate goal in this Phase I effort was to present a sound technological base for proceeding with development of Mini AMP which can lead to a successful development of a commercial product line. We feel this set of technologies will assure a leading role for WET Labs in providing integrated, reliable, comprehensive environmental sampling solutions to meet naval, research science, resource management, and ocean observing system needs. As such we view our efforts over this past five months as highly successful and look forward to further pursuing this quest.